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FLUORESCENCE AND MAGNETIC ROTATION SPECTRA OF SODIUM VAPOR, AND THEIR ANALYSIS.

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Presented by C. R. Cross. Received August 7, 1906.

Previous work, which has been recorded in the Philosophical Magazine,[1] convinced me that a careful study of the remarkable optical properties of the vapor of metallic sodium would, in time, furnish the key to the problem of molecular vibration and radiation. This opinion has been strengthened by the work of the past year, and though much remains to be done, it seems best to place the results already obtained on record. In no other case that I know of is the molecular mechanism so completely under the control of the operator. Its periodicities can be studied in a variety of ways: by absorption, by cathode-ray stimulation, by excitation with light, either white or monochromatic, and lastly by its remarkable selective magnetic rotation of the plane of polarization.

The vapor is, in every case, that obtained by heating metallic sodium in steel or porcelain tubes, usually highly exhausted. From a study of the dispersion of the vapor, it seems probable that we may be dealing with clusters of molecules with which a certain amount of hydrogen may be associated.

As I have shown in a previous paper,[2] if a pool of sodium is heated in a highly exhausted horizontal tube, the top of which is cooler than the bottom, the vapor has an enormous optical density close to the surface of the pool, and a very small density along the roof, the non-homogeneous layer acting as a prism. The only way in which I can reconcile this state of things with the kinetic theory is to assume that the vapor leaves the metal in the state of molecular clusters, which gradually break up into smaller clusters and eventually into molecules. This is of course only an hypothesis, and I mention it in the present paper merely to indicate that our vibrating mechanism may be an aggregate and not a single molecule. It is also possible that hydrogen atoms are associated with the sodium, for the work on the dispersion indicated that there was present always a small trace of some gas other than sodium, which no amount of pumping would remove; that is, it appeared to be tangled up in the sodium vapor, condensing with it in the cooler parts of the tube. All of this is, however, irrelevant, for we are for the present merely engaged with the study of a certain remarkable vibratory mechanism, and for the present need not concern ourselves whether it is a molecule, a cluster of molecules, or a compound molecule.

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[1] Magneto-optics of Sodium Vapor, Phil. Mag., Oct., 1905. The Fluorescence of Sodium Vapor, Phil. Mag., Nov., 1905.

[2] A Quantitative Determination of the Dispersion of Sodium Vapor, These Proceedings, **40**, 335.

We will begin by a description of the various spectra which we shall study and compare in the present paper. The spectrum region with which we are concerned lies between wave-lengths 4600 and 5700, i. e. the region of the green-blue channelled absorption spectrum.

The Absorption Spectrum.

Photographed with the twelve-foot concave grating, the absorption spectrum is found to consist of a multitude of fine lines, to the number of about 1500 in the region specified. Its appearance has been found to be profoundly affected by the presence of hydrogen or any inert gas. It is shown on Plate 1, Figure 1, *g*, photographed in the second order with a twelve-foot concave grating. In hydrogen at atmospheric pressure its appearance is shown by spectra *f* and *h*, the fluted appearance being very marked. In a high vacuum its appearance is shown by spectrum *b*, the flutings having entirely disappeared. The chief change appears to lie in the increased absorbing power of certain lines or groups of lines. Spectrum *d* is taken under nearly the same conditions, the sodium vapor being less dense, however. A careful study of the effect of the inert gas has not yet been made, and it is mentioned here only on account of its relation with the subject of the paper. Comparatively few of the absorption lines have any relation with the fluorescent and magnetic rotation spectra, the *ones concerned, however, being those which are affected by the presence of the inert gas.*

Moreover, both the fluorescence and magnetic rotation disappear, i. e. cannot be excited, when the sodium vapor is formed in an atmosphere of hydrogen or other inert gas. Of this matter more will be said later on.

The Magnetic Rotation Spectrum.

It was found last year that a number of vapors, showing fine and sharp absorption lines, when placed in a powerful magnetic field, rotate the plane of polarization for wave-lengths agreeing with that of the absorption lines, not all of the absorption lines showing this rotatory power, however. The arrangement of the apparatus for showing the bright-line magnetic spectrum of sodium is shown in Figure A.

A piece of thin seamless steel tubing of such a diameter as to slip easily through the hollow cores of the electromagnet, from which the conical pole-pieces have been removed, is procured. A short piece of small brass tubing is brazed into one end, through which the tube is exhausted.

A lump of sodium the size of a walnut is melted in an iron crucible, and poured out into a V-shaped trough made of thin sheet iron. As soon as the bar is solid it is placed in the iron tube, one end of which has been previously closed with a small piece of plate glass cemented on with sealing-wax. The tube is introduced into the magnet, the sodium bar pushed to a position midway between the helices, and the other end closed with a piece of glass in a similar manner. The ends of the tube should be coated while hot with sealing-wax before the introduction of the sodium. One has then only to wave a Bunsen flame over them and press on the piece of glass, previously heated; the sealing-wax should come into optical contact with the glass to insure an air-tight joint. The tube is now connected with an air-pump which will produce a vacuum of a millimeter or two. If the air-pump leaks, it is a good plan to place a glass stopcock between the pump and tube to prevent the entrance of traces of air after exhaustion. For purposes of demonstration it is sufficient to heat the tube gradually with a Bunsen burner turned down low. In the present work, however, where constancy of temperature was essential, electrical heating was invariably used.

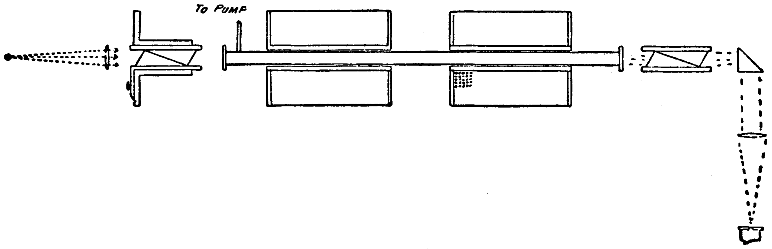


Figure A.

The light from an arc-lamp, made parallel by a lens, is passed through a Nicol prism, the steel tube, and a second nicol, after which it is brought to a focus by means of a second lens upon the slit of a spectroscope. With the steel tube cooled below the point at which sodium vapor forms, the nicols are set for complete extinction, and the field of the spectroscope becomes dark. The tube is now heated and the magnet turned on, the air-pump being worked occasionally to remove the hydrogen which is given off from the sodium. A bright yellow spot will appear on the slit of the spectroscope, which is seen to be made up of radiations chiefly in the immediate vicinity of the D lines. The phenomena at the D lines have been fully described in the paper already alluded to (Magneto-Optics).

When the vapor acquires a considerable density, a most magnificent bright-line spectrum appears in the red and green-blue region. Each bright line corresponds to a dark line in the absorption spectrum, but only a small percentage of the dark lines appears to exercise a rotatory power. Some of the strongest absorption lines are absolutely unrepresented in the magnetic rotation spectrum, which indicates that there is some radical difference in the absorbing mechanism.

It is with the bright-line spectrum in the green-blue region that we are now concerned. This spectrum has been photographed with the large, three-prism long focus spectrograph, and also with the twelve-foot concave grating. Reproductions of the prism spectrograms are given on Plate 2, *f* and *m*. The magnetic spectrum made with the large grating and the absorption spectrum recorded on the same plate are reproduced on Plate 1, *c* and *d*.

Only about sixty lines appear in this spectrum in contrast to the 1500 in the absorption spectrum. The intensities are very variable, and apparently bear no relation to the intensities of the corresponding absorption lines. The rotatory lines in many cases coincide with the heads of the groups of absorption lines, though the centre of the line appears to be slightly displaced beyond the head of the group of absorption lines. The displacement is, however, very slight, not more than half the width of the line. A list of the wave-lengths of all the lines visible on the negative is given on page 239. The approximate intensities are represented by numerals, 10 indicating the maximum intensity and 1 the minimum.

At first sight there appears to be no regularity whatever in the distribution of the lines, except perhaps above wave-length 502, where they appear to be about equally spaced in small groups of three or four lines each. Without the aid of the fluorescence spectra of the vapor excited by monochromatic light, it is doubtful whether any regular series of lines could be found in the magnetic spectrum, for, as has been subsequently found, more than half of the lines in the series are absent, and there are six or more series present. The fluorescence spectrum with white-light excitation is shown on Plate 1, *e*, which is from a negative made with the twelve-foot grating. As will be seen, the bright lines coincide with the bright lines of the magnetic spectrum, though much broader. It will be easier to explain how the series were picked out after we have commenced the study of the fluorescence. I have added to Plate 1 spectrum *i*, the magnetic spectrum with the series indicated. There appear to be five distinct series and a number of lines which thus far have not been brought into any definite relation with one another. These series we will number 1, 2, 3, 4, and 5. All the lines belonging to the first series have one dot under them, those belonging to the second have two dots, etc. These series are shown separated on the chart (Plate 5) at the top. Absent lines are indicated thus : ◊.

GREEN ROTATION SPECTRUM.

1	5225.34
1	5218.49
1	5212.02
1	5186.70
1	5179.71
1	5172.98
1	5171.98
1	5169.04
1	5165.85
1	5147.50
1	5140.71
3	5133.73
3	5126.54
2	5119.34
1	5095.70
2	5094.78
7	5087.31
7	5079.78
2	5071.58
1	5052.83
1	5049.56
5	5048.49
7	5040.65
2	5033.54
2	5025.66
3	5003.12 broad
10	5001.57
5	4979.34
2	4970.85
1	4967.10
1	4964.39
9	4962.85
1	4958.62
4	4933.93
5	4932.64
3	4924.32
4	4912.10
1	4904.67
1	4903.38
1	4896.65
1	4894.58
1	4892.77
2	4883.81
3	4865.59
2	4839.56
9	4837.49
2	4819.43
1	4814.60
1	4812.68
3	4810.16
3	4802.62
5	4792.67
3	4782.89
1	4777.00
1	4766.94
6	4756.69
1	4752.04
2	4738.51
4	4727.52
1	4716.90
1	4715.63
1	4703.78
2	4692.54
2	4670.30

The fifth series is at the top, the fourth next, and so on down, the extra lines being indicated in the lower row. This arrangement is considered provisional: it is the best that I can do at the present time, and I believe that it is correct in the main. We shall see presently, however, that photographs of the fluorescence stimulated by monochromatic radiation will have to be made with the large concave grating before we can be absolutely sure of all of the lines. We will drop the magnetic spectrum for the present and consider

The Fluorescence Spectrum.

In the previous paper I have described some of the remarkable changes which take place in the distribution of energy in the fluorescence spectrum of sodium vapor when the wave-length of the exciting light is changed. With white-light stimulation the general appearance of the spectrum is shown in Plate 4, Figure 6, A. There is, in addition, a broad double band at the position of the D lines, and a red-orange spectrum which, when the vapor is dense, is distinctly banded. In the present paper we shall be concerned chiefly with the portion figured above, for it is in this region that most of the remarkable changes occur. As will be seen, it is comprised between wave-lengths 460 and 570, and is devoid of any apparent regularity in the distribution of its lines, except in the region above $\lambda = 505$ where we have lines spaced with considerable regularity, the spacing becoming less as the wave-length increases. The distribution of intensity in this portion of the spectrum is such as to give it a fluted appearance, the flutings being most conspicuous in the region between $\lambda = 505$ and $\lambda = 535$. With white-light stimulation the flutings cannot be made out above 540, as can be seen from Plate 4, Figure 6, B, in which the upper limit of this part of the spectrum is shown. The fine lines are present in this region, becoming, however, less and less distinct as the upper limit of the spectrum is approached. If, now, instead of stimulating the vapor with white light, we employ blue light in the region 460–465 obtained from a spectroscope for the excitation, the fluorescent spectrum presents a totally different appearance (Figure 6, C). The blue region, corresponding in its range to that of the exciting light (indicated by a double arrow), appears as before, and the upper limit of the spectrum between wave-lengths 540 and 565, *the intermediate portion being entirely absent*, as shown in the lower spectrum of Figure 6, C. Furthermore, at the upper or yellow end, there now appear the flutings, which were absent when the fluorescence was stimulated with white light.

If, now, we gradually increase the mean wave-length of the exciting light, the region of maximum intensity in the fluorescence spectrum moves down from the yellow into the green, as is shown by the remaining photographs in Figure 6, C. Moreover, as I pointed out in the previous paper, the positions of the fluted bands change slightly, the positions of the individual lines which make up the bands remaining fixed however, the shift resulting from a change in the distribution of intensity among the lines. The reason of this curious phenomenon will appear when we come to the study of the fluorescence spectrum excited by strictly monochromatic radiations.

The spectrum stimulated by white light I have named the "complex fluorescent spectrum," for it has been found that it is a superposition of a number of simpler spectra, any one of which can be independently excited by suitably controlling the wave-length of the stimulating light. Indications of something of this sort were found last year, and were described in the preliminary paper. An insufficient number of photographs were obtained, however, at the close of the university year, to make anything like a complete analysis of the complex spectrum possible.

During the past winter and spring a careful study has been made of the relations existing between the complex fluorescent spectrum, the absorption spectrum, and the bright-line rotation spectrum described in the earlier paper. The fluorescent spectrum has at last been photographed with the twelve-foot concave grating, enabling a study to be made of its more minute structure.

Some very remarkable effects have been observed with monochromatic stimulations obtained by the isolation of certain lines from metallic arcs, which yield comparatively simple fluorescent spectra made up of widely separated sharp lines, placed in many instances at nearly equal intervals along a normal spectrum. A given series of lines can be brought out by stimulating with light of any wavelength corresponding to that of some line in the series, but when the stimulations occur at certain points, some of the lines may be absent, gaps appearing in the series. The most conspicuous example is the case of stimulation with the cadmium line 480, which will be considered in detail presently. It will be remembered that certain lines are absent in each series, in the magnetic spectrum.

The apparatus employed in the experiments was essentially the same as that used in the earlier work. It consisted of a seamless tube of thin steel three inches in diameter and thirty inches long, with a steel retort at its centre in which a large amount of sodium could be stored. The retort was made by fitting two circular disks of steel to a short piece of tubing, just large enough to slip snugly into the larger tube. The circular ends of the retort were provided with oval apertures, as shown in Plate **3**, Figure 1. The retort was half filled with sodium, the molten metal being poured in through one of the apertures. It was then introduced into the tube and pushed down to the centre, after which the plate-glass ends were cemented on, as shown in the figure. This arrangement prevented the rapid diffusion of the vapor, and enabled a large supply of metal to be kept at the centre of the tube. The tubes used in the earlier work required re-charging after two hours' continuous operation, while the retort tube could be operated for several hundred hours on a single charge.

The tube was exhausted with a Fleuss pump and heated at the centre with a large burner, the ends being kept cool by jackets of absorbent cotton which dipped into pails of water.

The illuminating beam of either white or monochromatic light was focussed just within one of the oval apertures of the retort, falling upon the opposite wall a little to one side of the other aperture. By covering the further end of the tube with a black cloth, the fluorescent spot showed against the dead black background of the second oval aperture, and its spectrum was therefore uncontaminated with the exciting radiations.

A large three-prism spectrograph was constructed for photographing the spectra. The prisms were of clear dense flint four inches in height, and the focal length of the lenses thirty-six inches.

Since only lenses such as are used for telescopes were available, the spectrum lines are not so sharp as one would wish, except near the axis of collimation. By adjusting things so that the centre of the fluorescent spectrum fell at this point, the definition was pretty fair throughout its extent, and wave-lengths could be determined with an error not greater than one or two Ångström units.

The photographs of the complex spectrum of the fluorescence excited by sunlight, obtained with this instrument (Plate **4**, Figure 6), showed peculiarities which made it appear of the utmost importance to study the spectrum under higher dispersion. The green fluorescent spot had, after repeated improvements in the apparatus, attained such brilliancy that I felt sure that records could be obtained with the twelve-foot concave grating. An all-day exposure was found to be sufficient, the resulting spectrogram, with the iron comparison lines and the wave-length scale, being reproduced on Plate **1**, Figure 2. The scale was printed separately, and slight errors occur, due to stretching and shrinking of the prints. They are not greater in any case than 1.5 A. E. This plate shows the minute structure of the complex spectrum, and enables us to measure the wave-lengths of the bright lines with far greater accuracy than could be done with the plates made with the prism spectrograph. As much of the detail is lost during the process of reproduction, I have prepared a very careful drawing of one of the groups of bands at wave-length 5200 (Plate 4, Figure 5). The drawing was made from a print with the aid of a hand magnifier, and the peculiarities shown are found throughout the entire spectrum.

The bright lines are sharp, and quite as narrow as the iron lines of the comparison spectrum. We must remember, however, that the slit was not very narrow, 0.2 mm. perhaps, and it is quite possible that a further contraction would not decrease the width of the fluorescent lines. Each bright line is in general accompanied by two lateral wings, which terminate quite sharply, the narrow spaces between every two adjacent wings appearing as narrow dark lines. These wings do not in general appear with strictly monochromatic stimulation. In the work of last year, when studying the remarkable changes which occur in the spectrum stimulated with the fairly homogeneous light furnished by the monochromatic illuminator with very narrow slits (see previous paper), I observed that as the wave-length of the light was very gradually altered, the fluorescent lines appeared with wings first on one side and then on the other, the change in the appearance of the line reminding one of a flag flying first on one side of the mast and then on the other. With the strictly monochromatic illumination obtained with the isolated metallic arc lines, the fluorescent lines are usually devoid of wings, though in some instances the wings are found, and sometimes the wings appear without the lines. These circumstances appear to indicate that the wings are due to the stimulation of the electron by frequencies slightly greater and slightly less than its own natural frequency.

I have not yet had time to repeat last year's experiments with the monochromatic illuminator, and plan to make a further study of the changes which accompany very gradual changes in the wave-length of the exciting light. The observations are very difficult and uncertain, as the light furnished by the monochromatic illuminator is not very bright when its slits are made as narrow as possible and the fluorescence spectrum can only be observed by carefully rested eyes. Probably by using a large prism spectroscope as an illuminator better results can be obtained. What is most desired is a light siren!

Analysis of the Complex Spectrum. Stimulation with Monochromatic Light.

It was found impracticable to use the monochromatic illuminator for the study of the simple spectra which made up the complex spectrum. Even with its slits very narrow, the wave-length range of the emitted light was wide enough to cover several of the absorption lines of the vapor. The earlier work had shown that the light of the cadmium spark was capable of exciting fluorescence, and experiments were accordingly started with metallic arcs. Just at this time came the very opportune invention of the fused quartz metallic arc lamps by Stark, working in the Heraeus laboratory at Hanau. Two of these lamps were immediately ordered, one filled with cadmium, the other with zinc. Their form is shown on Plate 3, Figure 1. The lamp is kept in communication with a mercury pump during its operation and stands in a disk of water. The cadmium lamp worked well on a circuit of 110 volts direct, but the zinc lamp gave better results on the 220. They are started by a small induction coil, one terminal of which is connected to the negative pole of the lamp, the other twisted around the quartz U tube. A blast lamp is directed against the tube until the portion above the metal electrodes is red hot, the coil is then started, and the arc usually forms at once. As exposures of eight or ten hours were often necessary, and the lamps have a trick of going out every half-hour or so, an automatic starter was devised, which turned on the coil the moment the lamp went out. As soon as the arc struck again, the coil was stopped. This arrangement is figured on Plate 3, Figure 2, and consisted of a small electromagnet in circuit with the lamp, which pulled a steel spring away from a brass screw as long as the lamp burnt. The spring and screw were inserted in the primary circuit of the coil.

The cadmium lamp burns with a greenish-blue light of dazzling brilliancy, the zinc lamp with a curious purple light, which causes all the woodwork in the room to appear blood-red, while most other objects appear bluish white or purple. Both lamps excite a brilliant fluorescence of the sodium vapor when their images are thrown upon the oval aperture of the retort. In this case the fluorescence is excited by several different radiations. Various devices were used for picking out one line at a time. The cadmium radiations which are capable of exciting fluorescence have wave-lengths 5086, 4800, and 4678. Color screens and the Fuess monochromatic illuminator, as well as the thin crystals of chlorate of potash (described in the Phil. Mag. for June), were tried; also a block of quartz, cut perpendicular to the axis, placed between two nicols. The arrangement which gave the best results, and appeared to be accompanied with the least loss of light, is the one figured on Plate 3, Figure 2. One vertical tube of the lamp is used as the source, the light from which, after collimation, passes through a large bisulphide of carbon prism, and is focussed upon the retort by an achromatic telescope objective with an aperture of 12 cms. and a focal length of 2 metres. The dispersion of the prism was sufficient to separate completely the monochromatic images of the lamp, any one of which could be thrown into the aperture, the light passing by the edge of the 90° prism by means of which the fluorescent light was reflected through a lens and thence upon the slit of the spectroscope.

The sources of light which have thus far been successfully employed in stimulating the fluorescence of the vapor are the following : quartz arc lamps containing cadmium, zinc, and thallium; ordinary arcs between lead, silver, bismuth, and copper electrodes; lithium, sodium, and barium arcs, and vacuum tubes containing helium and hydrogen.

Unfortunately the quartz lamps are very expensive, and become almost useless after a run of about thirty hours, the surface becoming granular and an opaque black deposit forming on the inner walls. As exposures of eight hours are sometimes necessary, it will be seen that lamps at $30 apiece, with an average life of thirty hours, make the investigation an expensive one.

The photographs of the fluorescent spectra obtained with monochromatic stimulation are reproduced on Plate **2**.

After each exposure the D lines were recorded on the plate, so that the different spectra could be brought into coincidence for purposes of comparison : the D lines will be found at the extreme right in each spectrum. The photographs have been reproduced as negatives, and the point or points coinciding with the wave-lengths of the stimulating light are indicated by arrows. A large scale drawing or chart of the most interesting of these spectra, together with others too faint for reproduction, has been made on cross-section paper, the points of excitation being indicated by arrows, as in the photographs (Plate **5**).

Drawings of the complex spectrum and the magnetic rotation spectrum made from the photographs obtained with the large concave grating will be found at the bottom of the chart : the former is a positive. At the top I have given a composite drawing which represents a superposition of all the simple fluorescent spectra thus far obtained. Immediately below it will be found the spectra excited by the complete radiation of the cadmium and zinc tubes. In each case there are three different exciting radiations simultaneously applied, yet it is almost impossible to find two fluorescent lines which coincide. The other spectra are excited for the most part by a single monochromatic radiation, the wave-length of which is indicated by the arrow. I have not yet obtained photographs of the fluorescent spectra excited by the separated radiations of the copper arc or by the separated zinc lines 468 and 472; consequently these have been drawn together. It is possible, however, by comparing the spectrum excited by copper with the one excited by zinc 4811, to make a guess as to which lines belong together.

We will begin by a study of the spectra excited by the cadmium radiations.

CADMIUM STIMULATION.

Photographs of the fluorescent spectrum obtained with the cadmium-arc excitation are shown on Plate **2**, *h*, *i*, *j*, *k*.

Of these, *i* and *k* are excited by all three cadmium lines; the former taken with a much narrower slit than the latter. Spectrum *h* was taken when the sodium vapor was excited by the line 480; observed visually, it consists of twelve bright lines, in groups of two and four, as shown on the chart immediately above the complex spectrum at the bottom. Midway between the groups very faint lines can be perceived if the eye is carefully rested. The strong lines are arranged thus: two, absent line, four, absent line, two, absent line, four. The absent lines, or, more correctly speaking, the faint lines, evidently belong to the same series, and taken collectively the lines will be found to be very nearly equidistant, measured along a *normal spectrum*.

The wave-lengths of the lines in this series, as determined from measurements of the plates obtained with the prism spectrograph, are as follows:

λ.	λ differences.	λ.	λ differences.
4760		. . .	$\frac{76}{2}$ 38
4800	 34	5095	
4838	 38	5133	 38
. . .	$\frac{70}{2}$ 35	. . .	$\frac{74}{2}$ 37
4908		5207	
4946	 38	5245	 38
4983	 37	5283	 38
5019	 39	5321	 38

These wave-lengths I consider to be accurate to within about 2 A. E. or $\frac{1}{3}$ of the distance between the D lines.

It is, of course, of the utmost importance to determine the law which governs the spacing of the lines in the simple spectra. A criterion may perhaps be obtained by referring to the magnetic rotation spectrum of the vapor, the lines of which correspond in general to the lines of the fluorescence spectrum. This spectrum has been photographed with a large concave grating and the wave-lengths determined certainly to within a tenth of an Ångström unit. The strong lines at the following points of the spectrum form a series analogous to the series obtained with the cadmium 480 series.

λ.	λ differences.
5119.34	
5079.78	39.56 A. E.
5040.65	39.13
5001.57	39.08
4962.85	38.67
4924.32	38.52

This we have called the first series.

The wave-length differences are, in this case, much more nearly constant, and decrease progressively.

The lines of this series are especially conspicuous in the magnetic rotation spectrum (Plate **1**, Figure 1, *c*), hence I have mentioned it first; they appear in the fluorescence excited by the lead line 5001, as will be seen by reference to the chart, Plate **5**.

If now we try to fit one of the magnetic series to the cadmium 480 fluorescence series, we find that the third magnetic series coincides with it between 5019 and 5134, while in the violet region it coincides with the fourth magnetic set. I do not feel sure whether this peculiarity is due to slight errors in the determination of wave-lengths or not. I think not, however, for I have very carefully superposed the two negatives (cadmium fluorescence and magnetic rotation spectra), both taken with the same instrument, and find the same disagreement. We cannot be sure of anything, however, until the cadmium series has been photographed with the grating. During the coming year I expect to photograph the fluorescence spectrum excited by cadmium and zinc radiations with the large concave grating. It will then be possible to determine the wave-lengths of the lines to within a tenth of a unit.

One of the most remarkable facts connected with the appearance of the lines of a series is that the distribution of energy among the individual lines depends upon the point of excitation. Unfortunately there are very few arc lights bright enough to excite fluorescence. It was found, however, that the silver line 5207, which coincides with one of the fluorescent lines of the cadmium 480 series, was bright enough for the purpose. The silver was carefully freed from copper, as the neighboring copper lines are powerful exciters; in their absence, no prismatic separation was necessary, as the rest of the silver lines were inoperative. A photograph of the fluorescence spectrum obtained with silver stimulation is shown on Plate **2**, *g*. The series in this case *has no gaps* in it, the line at 5170, which is absent with cadmium excitation, coming out strong (see chart as well). The monochromatic illuminator, with its slits reduced to the width of a hair, was arranged to furnish light of wave-lengths corresponding to other lines in the series, and photographs obtained which are recorded on the chart. It will be seen that faint or missing lines occur in each case, but that their position varies with the point of excitation. If we consider each line caused by a single electron or vibrator, the phenomena suggest that the vibrators are united in some way, perhaps in a closed ring, and that when the system is set in vibration there are nodal points, the position of which depends upon the point in the chain where the periodic force is applied. Moreover, as has already been pointed out, if the force is applied at the "high frequency" portion of the chain, the regions excited are those of highest and lowest frequency, the intermediate portion appearing to be at rest. This is especially noticeable in the case of the bismuth excitation. (Plate **2**, *e*, and chart.)

In addition to the lines enumerated above, there are a number of others at the upper end. These do not appear to be distributed with the same regularity, though some of them may form an extension of the series, or more probably may be the beginnings of other series. In general it has been found that in the simple spectra the lines are regularly spaced between the extreme violet end and a point at about $\lambda = 5350$. Above this point the spacing is generally very irregular, and it is difficult to unravel the spectrum. Of this more will be said later.

We will next take the fluorescent spectrum excited by the green cadmium line 5086.

This spectrum is remarkable in that it is made up of eleven pairs of lines regularly spaced (Plate **2**, *j* and chart). The other two cadmium lines appear on the plate, as the spectrograph was not shielded from the diffused light from the lamp.

A series in the magnetic spectrum coincides with the series formed by the shorter λ member of each pair. The wave-lengths and differences are given in the following table:

λ.	λ differences.	λ.	λ differences.
5165.85		. . .	$\frac{77.64}{2}$ 38.82
5126.54	39.31	4970.85	
5087.31	39.23	4932.64	38.21
5048.49	38.82	4894.58	38.06

I am quite at a loss as to how the series formed by the other members of the doublets is originated. It appears to coincide with the series excited by helium 5014, as will be seen by reference to the chart. It appeared at first as if the exciting line might lie between two adjacent fluorescent lines, and in that way excite a double series, but cadmium 5086 is slightly on the short λ side of the magnetic line 5087.3, while the wave-length of the other line of this pair is 5092, i. e. on the long λ side.

This is the only case recorded where a spectrum of doublets is excited by monochromatic stimulation, though I am of the opinion that the copper line 5152 behaves in the same way.

What is still more remarkable is the fact that if the excitation is at a different point we no longer get doublets. The lithium line at 4971 takes hold of one of the more refrangible components of one of the doublets, but only a single series of lines appears in the fluorescence spectrum (see chart). The other series, i. e. the less refrangible components, can be separately excited by stimulation with the helium line 5014 (see chart). If we are dealing with anything in the nature of electron doublets, we should expect both the lithium and helium radiations to excite a fluorescence showing double lines.

If we try to explain the phenomena by assuming two chains of electrons fastened together at the point 5086, we must account for the fact that the 5086 vibrator excites the other chain when it is acted upon by light of its own frequency, but not when it is vibrated by the lithium radiation acting at a different point on the chain. I have adopted this hypothesis of electron chains merely to aid in describing the physical phenomena, and not with much hope that it will explain anything.

It seems much more likely that the different lines represent vibrations of different frequencies of the same system. We must not try to make the molecule too much like a piano. The vibrations may be ripples running over its surface or they may be unlike anything with which we are familiar. If we had never seen a bell, it would be difficult to work out the theory of its very complicated vibrations from a study of a set of simple pendulums. Possibly stimulation at some other points might give rise to the double lines.

I attempted to do this with the monochromatic illuminator, but without success. The band of exciting light cannot well be made much narrower than the distance between the components of the doublets. Even with the instrument set at 5086, I could detect no evidence of the doublets. I am planning to investigate this matter further with a larger monochromatic illuminator designed to furnish more nearly monochromatic light.

In addition to the eleven pairs of lines in the fluorescence spectrum excited by cadmium 5086 there are two strong lines at wave-lengths 5305 and 5341. These seem to belong to the same series, and the former has a faint companion, the two forming a doublet. The line 5341 is also accompanied by a companion, which, however, is so faint as to be barely distinguishable.

The spectrum excited by the more refrangible of the two blue cadmium lines 4678 is reproduced only on the chart. It consists of a regular series of five lines in the blue region, and a large number of irregularly spaced lines of widely different intensities in the yellow-green region. None of these lines appear to be represented in the magnetic spectrum.

This spectrum illustrates well the characteristic peculiarity of the sodium fluorescence spectrum, that stimulation at the more refrangible end excites powerful fluorescence at the opposite end. The lines which form the regular series we may call directly excited, the others in the yellow region indirectly excited. The latter in all cases seem to be irregularly spaced. The great problem to solve is to determine the nature of the mechanism and find out how the low-frequency vibrators are set agoing by the stimulation of the high-frequency ones, while they remain quiescent when the stimulation is at the middle of the spectrum. Speculations on these points must be deferred for the present.

Zinc-arc Excitation.

The complete fluorescent spectrum excited by all three of the zinc lines (i. e. the total radiation of the lamp) is shown near the top of the folding chart, just below the cadmium fluorescence. It is scarcely possible to find a coincidence of two lines. The two spectra placed side by side make a striking picture of the variation produced by different excitations of the same fluorescing medium. A photograph of the spectrum is reproduced on Plate **2**, *c*.

Exciting with the zinc line 4811 alone gives us the spectrum shown on Plate **2**, *b*. The other two zinc lines are of course present on account of diffused light. Referring now to the chart, we find that the violet end of the spectrum agrees pretty well with the fifth magnetic series, though other lines are present. The two strong lines at 5188 and 5225 also appear to belong to the same series. The lines on the whole are much less regularly distributed than in the case of the cadmium 480 excitation. The three wide pairs between 523 and 535 are peculiar to this excitation.

The fluorescence excited by the other two zinc lines, 4680 and 4722, is also recorded on the chart. These lines are so close together that it was found impossible to illuminate the vapor with light from but one of them, and have at the same time sufficient illumination to excite much fluorescence. I have not yet found much evidence of regularity in the distribution of the lines in this case, though there is undoubted evidence of two series in the immediate vicinity of the exciting lines. I have indicated with the letters A and B the lines which appear to belong together (compare with helium excitation). We have an enormous number of lines in the yellow-green region, since we have a double stimulation at the opposite end of the spectrum. There seems to be some regularity here, but it is difficult to say which lines belong together.

BISMUTH EXCITATION.

The light of the bismuth arc makes a beautiful stimulus for the fluorescence, since it contains but a single operative line, the strong one at 4724. It gives rise to a very regular series in the blue-violet region, the lines appearing to fall midway between the lines of the third and fourth magnetic series (Plate **2**, *e*, and chart). Though the wave-length of the exciting line is only two Ångström units longer than that of the zinc line 4722, the spacing of the series in the two cases is quite different. The same thing has been noticed in the case of the shortest cadmium and zinc lines, which makes it seem possible that interesting results may be obtained by altering the wave-length of the exciting line, either by pressure or a powerful magnetic field. Experiments in this direction will be made next winter.

In both of these cases, in each of which we have excitation by lines of nearly the same wave-length, the wider-spaced series is produced when the stimulation is by the longer wave-length. It remains to be determined whether we take hold of different absorption bands and excite entirely different series, or whether we stimulate the same vibrator in each case, the spacing of the resulting lines depending upon how nearly we approach its natural period in our exciting vibrations.

In addition to the regularly spaced lines in the violet, we have a complex assortment of lines in the yellow-green region, the intervening portion being totally devoid of lines. One of these lines, $\lambda = 5300$, has a broad diffused wing, and it is perhaps worthy of remark that in the spectrum excited by the two zinc radiations we have a hazy doublet at this point, in the spectrum excited by zinc 4811, a single line, and in the spectrum excited by cadmium 480, two faint lines. Some of the other lines have wings, as will be seen from the chart, and at wave-length 546 we find a broad hazy band. All of these peculiarities complicate things, and I have drawn attention to them merely to show that we must not expect to explain matters by too simple a mechanism.

A word or two about the bismuth arc may not be out of place. Various plans were tried, such as immersion of the electrodes in water, burning in the carbon arc, etc. The best arrangement was found to be a shallow iron dish about 4 cms. in diameter (pounded from a piece of thin sheet iron), filled nearly full of molten bismuth, and kept hot over a small burner. The dish of metal formed the positive electrode, the negative being a bar of iron which could be raised or lowered by a rack and pinion. The arc required constant attention, fresh metal being put into the dish every ten or fifteen minutes, and as exposures of eight hours were necessary, it will be seen that an enormous amount of very fatiguing work was necessary in all cases where open-air arcs were used.

Copper Excitation.

I have been unable thus far to obtain photographs of the fluorescence excited by the separated copper radiations. The lines are close together, and the arc climbs about over the electrodes. I hope next year to improve matters in this respect. On Plate **2**, *a*, is seen the fluorescence excited by the total copper radiation. Only the three green lines are operative in stimulating the vapor. The lines in the fluorescence spectrum appear to bear no very definite relation to the lines of the magnetic spectrum, as will be seen by the chart. There are many coincidences, however, with lines in the spectrum excited by zinc 4811, and by zinc 468 and 472. By comparing the three spectra I have made a provisional determination of the lines which belong together in the spectrum excited by the copper radiation. These lines are indicated by crosses and vertical dashes placed above them; other lines, which do not appear in the zinc spectra, have not been marked. I suspect that excitation with copper 5152 will produce a doublet at this point, and probably at other points, just as does cadmium 5086. An attempt will be made to verify this surmise. I have on one or two occasions, when trying to stimulate the vapor with this isolated line, been of the impression that I saw doublets distinctly, but at the time I attributed it to incomplete separation of the exciting lines.

Lead Excitation.

A lead arc, operated in a manner similar to the one described for bismuth, was used for exciting the vapor. The only line operative was the one at 5001, and it gave rise to a well-marked series of fluorescence lines, which coincided exactly with the first series of the magnetic rotation spectrum. It is worthy of remark that one of the extra lines of the magnetic spectrum lies very close to the exciting line, yet none of these lines appeared in the fluorescence spectrum. The fluorescence excited by lead was very feeble, and even with an eight-hour exposure the lines were very faint.

Helium Excitation.

A large "end on" helium tube with a 3 mm. bore was constructed for the investigation. This tube could be run continuously with an induction coil yielding a heavy ten-inch spark. An exposure of about twelve hours was given. Two of the helium lines are operative: line 5015 gives a well-marked series, the lines of which fall exactly midway between the lines of the second and third magnetic series; line 4713 gives a good series in the blue and at least six distinct lines in the yellow-green, the wave-lengths of which can be seen from the chart. The exciting line in this case coincides with one of the lines in the spectrum excited by zinc 468, and there is perfect agreement in position between the fluorescent lines in both cases, not only in the blue, but also in the yellow-green region. The lines in the spectrum excited by line 468, or at least as many as could be identified, have been marked. The identification was of course made by comparison with the spectrum excited by helium.

Lithium Excitation.

An arc was caused to play between a carbon rod and a large carbon block on which the lithium salt was placed. The image of the red flame was projected upon the window of the retort and excited a bright fluorescence. Two of the lithium lines were operative, — one at 4601, the shortest monochromatic stimulation thus far found, which gives the series in the violet (see chart), and a large number of lines in the yellow-green; and another at 4971, which gives a beautiful series in the green, coinciding exactly with the second magnetic series. The 4971 stimulation should be especially interesting, since there are several lines in the magnetic spectrum very close to it. The line is unfortunately not very bright, and the fluorescence lines were so feeble that they could only be measured with difficulty.

The lines in the yellow-green region are also of considerable interest, since they result from a single monochromatic stimulation applied practically at the extreme lower end of the fluorescence spectrum. In fact, this line is considerably below the limit of the fluorescence spectrum as usually seen with white-light stimulation: this limit is not far from wave-length 4670, which is the shortest thus far detected in the magnetic spectrum photographed with the grating, though faint lines are visible even below 4600 on negatives made with the prism spectrograph. There seems to be evidence of a number of series in the yellow-green region, the spacing, however, decreasing with increasing wave-length, just the opposite of the state of things which holds in the blue-green region. It is more likely, however, that the apparent decreasing of the spacing as the yellow end of the spectrum is approached is due to other series similar to those which are found in the green and blue, the nearness of the lines resulting from the large number of superposed series. With white-light stimulation no trace of the lines can be seen above wave-length 555, and they are so faint as to be almost indistinguishable for a considerable distance below this point. The broad flutings seen in the spectrum stimulated with white light are doubtless to be referred in some way to the circumstance that the lines of the different series get into and out of step periodically: they may thus be considered analogous to the bands seen when two diffraction gratings of slightly different spacing are superposed.

Barium Excitation.

The fluorescence excited by the barium arc appears to be due chiefly to the line 4934, which coincides with one of the extra lines in the magnetic spectrum. Line 4932 of the second magnetic spectrum is also very near it, and we find that the fluorescence spectrum contains lines which coincide with the magnetic lines of the second series, as well as lines which coincide with some of the extra magnetic lines. The barium arc contains a good many other fainter lines which may give rise to some of the fluorescent lines. It will be necessary to repeat the experiment with the 4934 line isolated.

Sodium Excitation.

As I showed in the earlier paper referred to, if we stimulate the vapor with intense sodium light, we obtain a yellow fluorescence which the spectroscope shows to be made up of two lines in the position of the D lines. We have here a re-emission of light of the same wave-length as the exciting light, and nothing else. This I have called resonance radiation, as we may find that it is different from fluorescence, though the two are doubtless intimately related. As there are several pairs of lines in the ultra-violet which belong to the same series as the D lines, it seemed of great importance to determine whether these appeared in the spectrum of the fluorescence excited by the sodium flame. The sodium tube was provided with a quartz window, and the light of the oxyhydrogen flame, heavily charged with sodium, focussed upon the aperture of the retort with a glass lens. White light from the arc was also used, as this excites the D line vibrations in the fluorescence. The spectrum was photographed with a small quartz spectrograph, and though the D lines were greatly overexposed, no traces of any of the ultra-violet doublets were found on the plate. Conversely, illumination with ultra-violet light in the region of the first ultra-violet pair of lines failed to produce any visible fluorescence. It was hoped that a faint yellow fluorescence might be produced in this way, due to emission in the region of the D lines. I have not yet tried stimulation with D_1 and D_2, alone, to see whether both D lines appear in the fluorescence. This will be a very difficult experiment, and I am saving it for the last. It will settle the question as to whether the principal series of sodium is a series of doublets or two series of single lines.

Cathode-ray Excitation.

The cathode rays, I find, excite a fluorescence similar to white light. The lines of the principal and subordinate series appear as well, some of them of overpowering intensity. The apparatus for the electrical excitation is shown on Plate 3, Figure 3.

It consisted of a steel tube 3 cms. in diameter and 35 cms. in length, one end closed with a glass plate, the other cemented with sealing-wax to a glass tube carrying the cathode. The mercury pump was kept in continuous operation to remove the hydrogen liberated from the sodium. On looking into the tube through the glass window a blazing spot of yellow light 2 cms. in diameter was seen at the point where the cathode rays entered the vapor. Its spectrum was photographed with the prism spectrograph, and is reproduced on Plate 2, *n*. In addition to the fluorescent spectrum, and the sodium lines of all three series, the hydrogen lines come out strong. I have never been able to eliminate them entirely. Very few experiments have been made on the electrical excitation, but some very curious phenomena have been observed. In some cases, by looking into the tube in an oblique direction, it was seen that at the point where the cathode rays entered the mass of vapor there was a bright green spot of fluorescent light, while at the point of exit there was an orange-yellow spot, *the intervening space being non-luminous.* Seen in a direction oblique to the direction of the rays, the two spots were seen completely separated. This I consider a very remarkable circumstance, and a spectroscopic study of the two spots of light will undoubtedly yield very fruitful results.

Unfortunately the condition is a difficult one to keep fixed, for the phenomenon only appears when the density of the sodium vapor is just right and the surrounding vacuum high. As I have shown in the paper on the dispersion of sodium vapor, we can have a dense mass of the metal vapor, bounded on each side by a very high vacuum, a very anomalous condition from the point of view of the kinetic theory of gases. My impression is that the green spot will show the fluorescent spectrum, and the yellow spot the lines of the principal and subordinate series, as found in the sodium arc, but as yet I have not found time to make even a visual examination. Several attempts have been made, but by the time the image of the spot was thrown upon the slit in the proper direction to pass the light through the prisms, and the eye brought to the instrument, the conditions in the tube changed.

It is difficult to account for the absence of luminosity of the centre of the mass and the two bright spots. Perhaps the condition under which the rays excite fluorescence exists only where the vapor mass is in contact with the vacuum, i. e. in the region where the hypothetical clusters of molecules are breaking up and flying to the cooler walls of the tube. Even assuming this to be the fact, the difference in the color of the two spots is still to be accounted for. Possibly the cathode rays excite the green spectrum, while the canal rays travelling towards the cathode excite the orange-yellow luminescence. I have made one experiment with a similar tube arranged so as to deliver a stream of canal rays against the vapor. The luminescence was bright yellow, but the tube cracked before a spectroscopic examination was made.

On the other hand, it may be that whatever causes the green luminescence is removed from the ray bundle by absorption, the residue exciting the yellow luminescence at the point of exit. If this is the case, we should expect the same amount of yellow light in each spot, and I am of the opinion that the green light is much too pure for this to be the case. Further experimenting will be necessary before it is possible to draw any very definite conclusions.

In the spectrum excited by the cathode rays the D lines are of immense brilliancy, running together into a single band of light. On each side of this are seen three or four symmetrically placed bands, decreasing in brilliancy as they recede from the D lines in each direction. No trace of these bands appears in the magnetic spectrum, which in this region shows only fine lines arranged in narrow groups, which do not coincide with the bright bands of the cathode luminescence.

A photograph of these bands is reproduced in Plate 4, Figure 4.

They have some connection with the D lines, I feel sure, for they are symmetrically arranged on each side of them. If the photograph had been made with a grating, we should of course call them ghosts. It may be that they are analogous to satellite lines, but if they are, we are certainly dealing with the phenomenon on a grand scale, for the fourth one is not far from the sodium doublet at 5688! All of these points will be more fully investigated during the coming year.

Other Possible Excitations.

It has occurred to me during the preparation of this paper that very interesting results would be obtained by exciting the fluorescence with the light selectively rotated by the vapor in a magnetic field, i. e. by the magnetic bright-line spectrum. This light is fairly intense, and it would be interesting to see whether the intensity distribution among the excited fluorescence lines was the same as in the magnetic spectrum.

What I most need, however, is a set of screens which will enable me to separate lines such as those of copper without resorting to the systems of prisms and lenses. A good collection of solutions of the rare earths would probably be very useful in the work. Erbium, praseodymium, and neodymium I have, but I should feel very grateful for the loan of any others which might prove serviceable, or for any suggestions regarding other possible sources of monochromatic light. As I have said before, the instrument most needed is a light siren!

Composite Excitation.

At the top of the chart just below the magnetic series will be found a spectrum containing about two hundred lines. This is a composite drawing made by superposing all of the drawings made of the simple spectra excited by monochromatic stimulation. It contains many lines not found in the complex spectrum excited by white light. In the latter, between wave-lengths 5000 and 5100, we find but ten or a dozen lines, while in the composite spectrum there are at least twenty. This circumstance is of interest in connection with the periodic dark regions of the complex spectrum, which give it a fluted appearance. The formation of these flutings requires further study, as their position shifts as we alter the wave-length of the exciting light, which in this case is a rather broad, isolated band from the continuous spectrum obtained with the monochromatic illuminator. The phenomenon was more fully described in the earlier paper, but requires further study.

The Series in the Magnetic Spectrum.

As we have seen, the complex fluorescent spectrum is made up of six or more series of lines, the individual lines of each series being about 38 Ångström units apart, the spacing becoming less as we pass from yellow towards violet. The fact that the lines in the magnetic spectrum coincide with the lines of the complex spectrum makes it seem certain that the same series will be found there. By comparing the various fluorescent spectra with the magnetic spectrum, and by measuring carefully the distances between the lines of the latter, I have made a provisional assignment of the magnetic lines thus far observed into five series.

The wave-lengths and wave-length differences are given in the tables on page 259.

As will be seen by reference to the chart, the first series has the largest *average* spacing, and the fifth the smallest, the "scale," if the term is allowed, decreasing gradually from the first to the fifth, the two coming into coincidence at about wave-length 4860.

Doubtless these series could be extended to wave-length 5500 or thereabouts by making use of the grating photograph of the complex fluorescence obtained by white-light stimulation. The lines are, however, so diffuse in their nature, with overlapping wings and other peculiarities, that I have not yet attempted any further extension. I think that by employing a much denser vapor the magnetic spectrum can be considerably extended, and as the lines are much sharper in this case, an extension of the series will be an easy matter. The other series necessary to give the close spacing found in the yellow may be discovered in this manner.

A theoretical discussion of the results will have to be deferred to a subsequent paper. In fact, I prefer to have this side of the subject attacked by those who have given especial attention to the theory of molecular radiation. The absence of many lines in each series in the magnetic spectrum, and the absence of certain lines in the fluorescent spectrum, are especially suggestive. We have similar conditions in other series of lines, as is well known, but the present case is, so far as I know, the only one in which we can, by varying the exciting conditions, bring about a change in the position of the absent lines. It appears to me that the data furnished us by sodium vapor ought in the end to enable us to choose between the various theories proposed to account for spectrum series.

The investigations recorded in this paper have been made possible

FIRST SERIES.

λ.	λ differences.
5119.34	
	39.56
5079.78	
	39.13
5040.65	
	39.08
5001.57	
	38.67
4962.85	
	38.52
4924.32	

SECOND SERIES.

λ.	λ differences.
5165.85	
	39.31
5126.54	
	39.23
5087.31	
	38.82
5048.49	
....	$\frac{77.64}{2} = 38.83$
4970.85	
	38.21
4932.64	
	38.06
4894.58	
....	$\frac{75.15}{2} = 37.57$
4819.43	
	36.54
?4782.89	
....	$\frac{112.89}{3} = 37.63$
4670	

THIRD SERIES.

λ.	λ differences.
5211.71	
	38.89
5172.82	
	39.09
5133.73	
	38.95
5094.78	
....	$\frac{115.34}{3} = 38.45$
4979.34	
....	$\frac{75.96}{2} = 37.98$
4903.38	
	37.79
4865.59	
....	$\frac{113.55}{3} = 37.85$
4752.04	
	36.41
4715.63	

FOURTH SERIES.

λ.	λ differences.
5219.00	
	39.29
5179.71	
	39.00
5140.71	
....	$\frac{115.05}{3} = 38.35$
5025.66	
....	$\frac{113.56}{3} = 37.85$
4912.10	
....	$\frac{74.61}{2} = 37.30$
4837.49	
....	$\frac{109.97}{3} = 36.68$
4727.52	
	34.98
?4692.54	

FIFTH SERIES.

λ.	λ differences.
5225.34	
	38.64
5186.70	
	39.20
5147.50	
....	$\frac{76}{2} = 38.00$
5071.50	
	38.00
5033.54	
....	$\frac{74.92}{2} = 37.46$
4958.62	
....	$\frac{74.81}{2} = 37.40$
4883.81	
....	$\frac{73.65}{2} = 36.82$
4810.16	
....	$\frac{71.66}{2} = 35.83$
4738.5	

EXTRA LINES.

5096.00
5052.83
5049.56
5003.12
4964.39
4967.10

through very generous aid given from the Rumford Fund by the American Academy of Arts and Sciences.

I am also under great obligation to my assistant, Mr. F. L. Cooper, for the many hours of very fatiguing work which he devoted to the research.

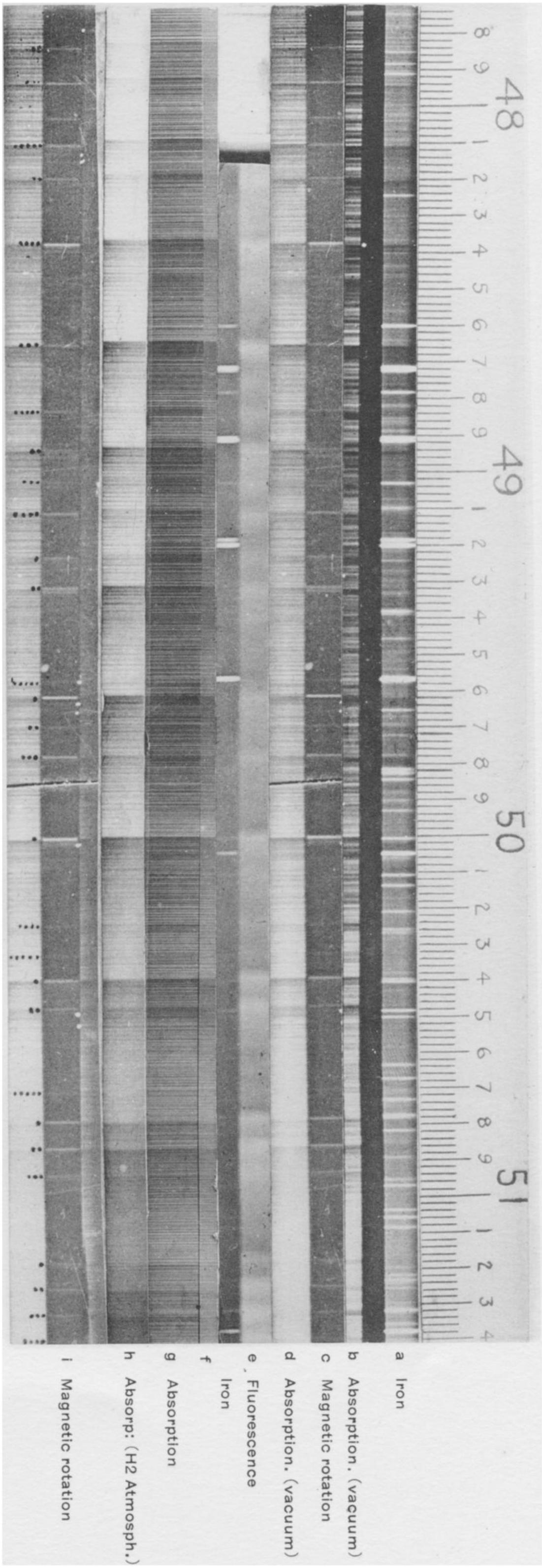


Fig. 1.

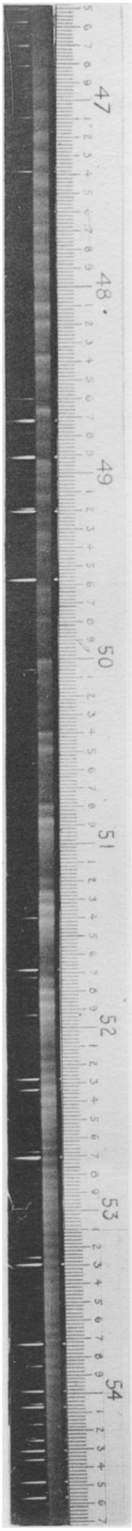
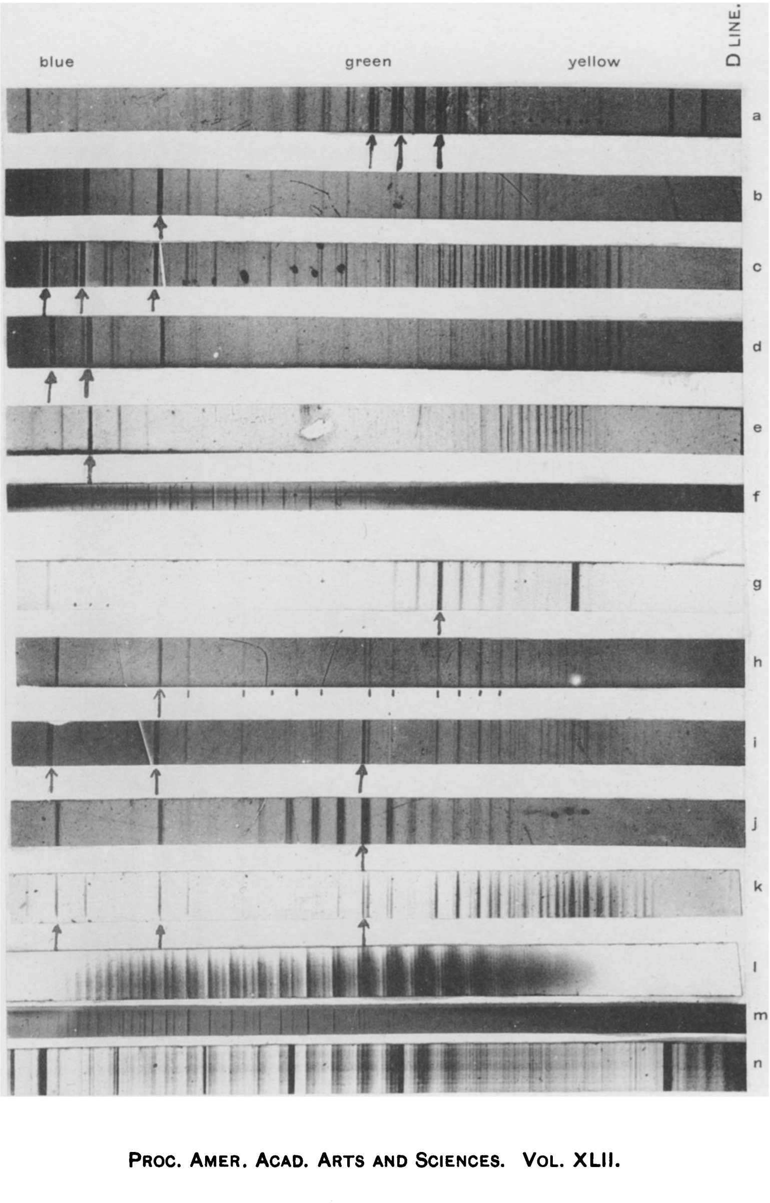


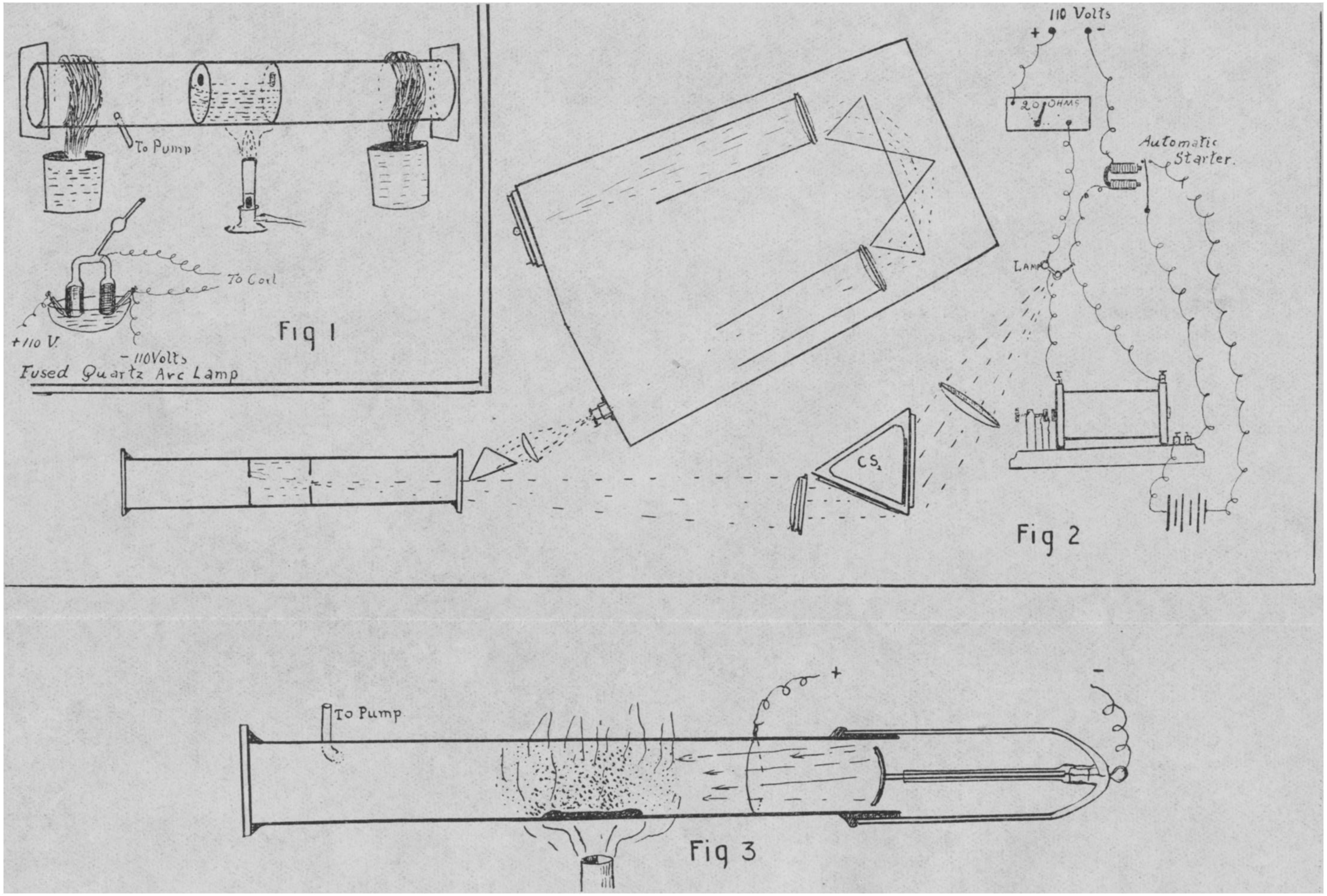
Fig. 2.

Fluorescence of Na. Fe Comparison.



HELIOTYPE CO., BOSTON.

PLATE 3.


To Pump
To Coil
+110 V.
- 110 Volts
Fused Quartz Arc Lamp
Fig 1
110 Volts
+
-
20 OHMS
Automatic Starter.
LAMP
CS_2
Fig 2
To Pump
+
-
Fig 3

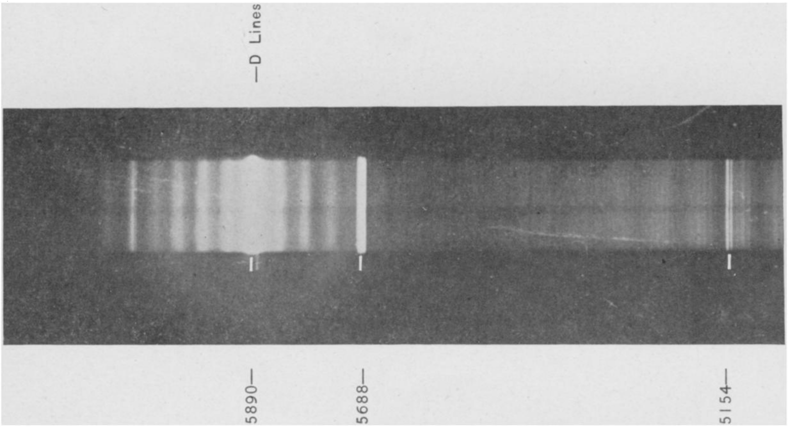


FIG. 4.

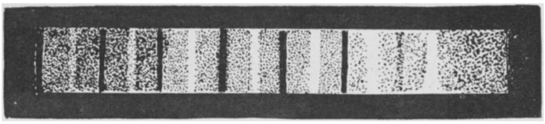


FIG. 5.

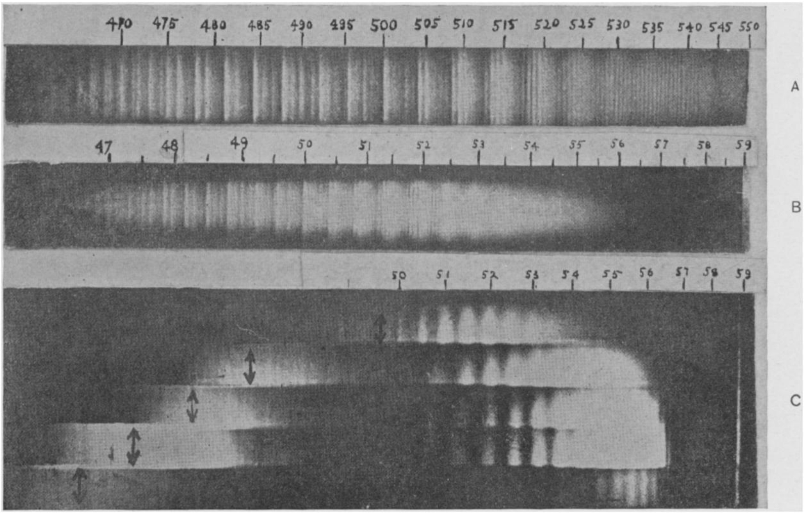
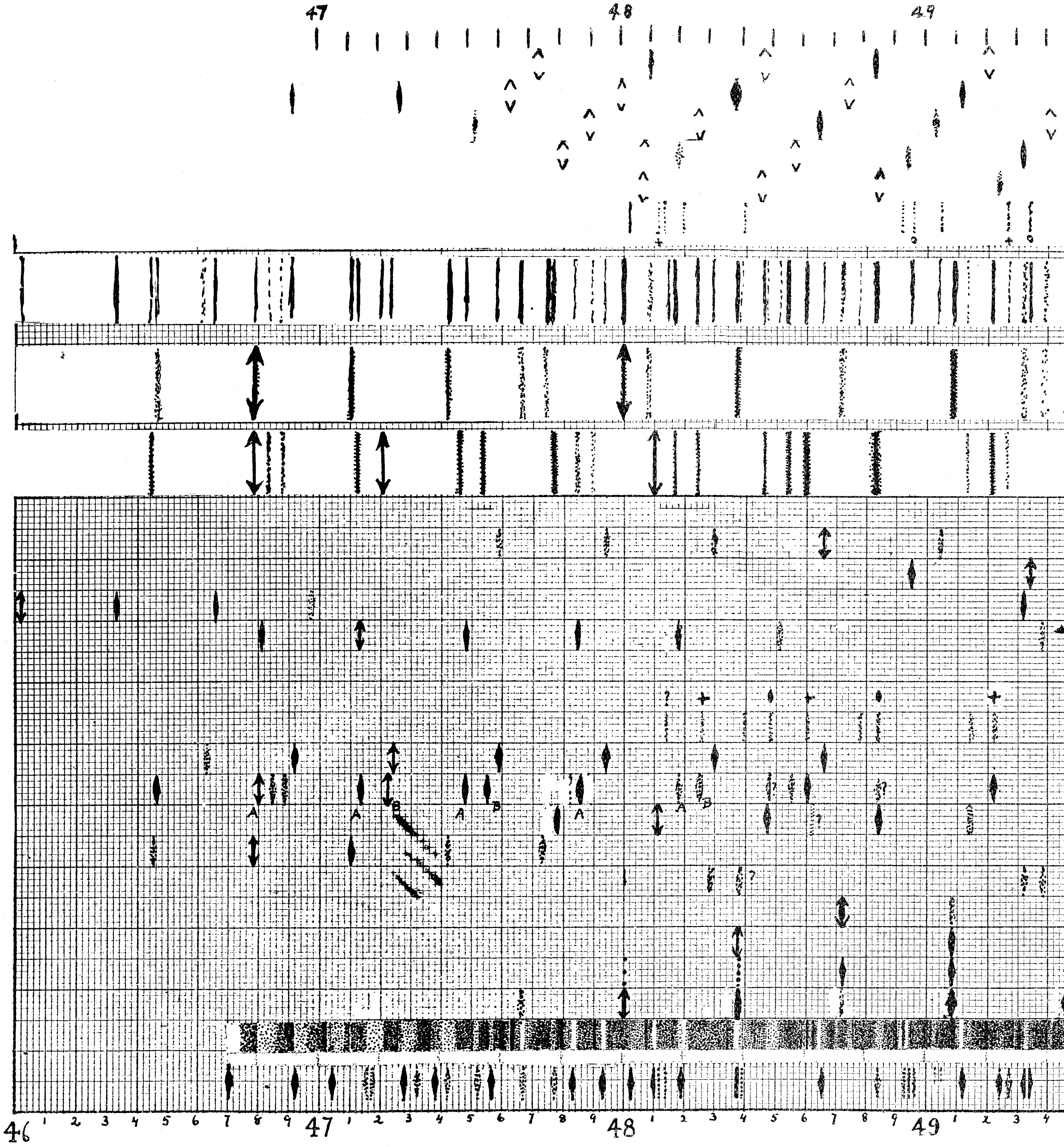
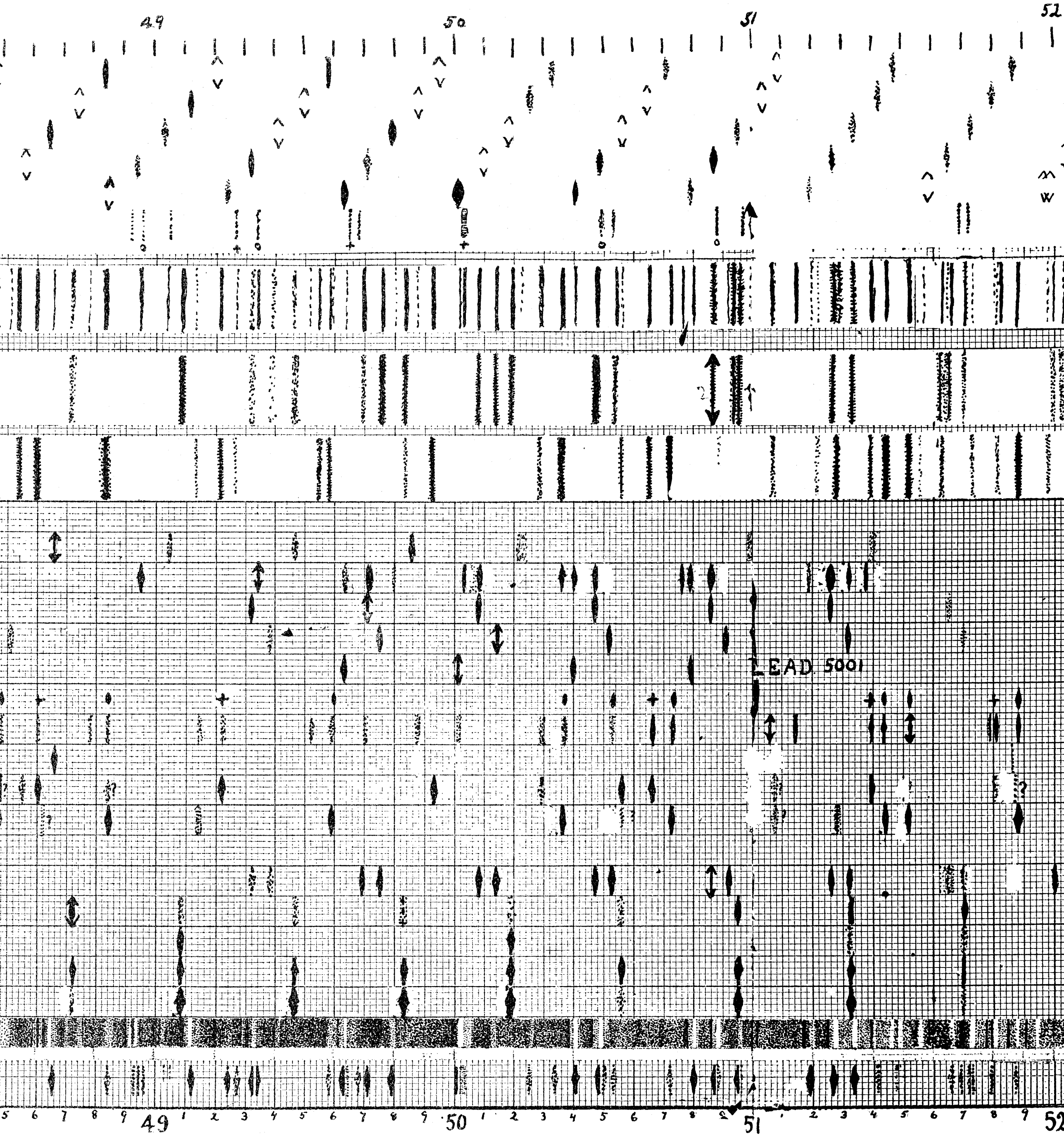


FIG. 6.

WOOD.—FLUORESCENCE OF SODIUM.




49
50
51
52
LEAD 5001
5 6 7 8 9 49 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 51 1 2 3 4 5 6 7 8 9 52

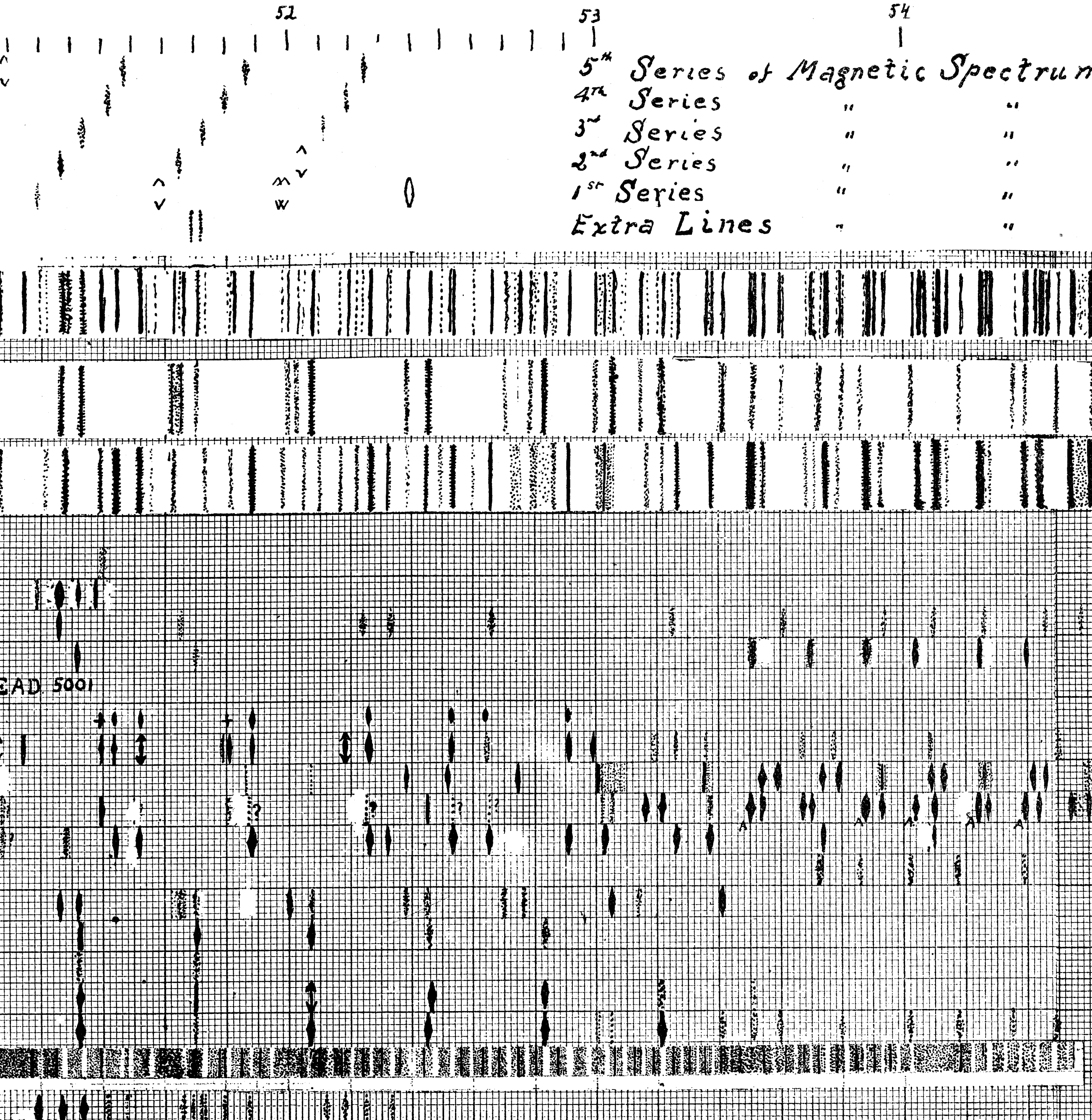

51
52
53
54
5th Series of Magnetic Spectru
4th Series " "
3rd Series " "
2nd Series " "
1st Series " "
Extra Lines " "
EAD 5001
52
53
54

PLATE 5.

54

Magnetic Spectrum.

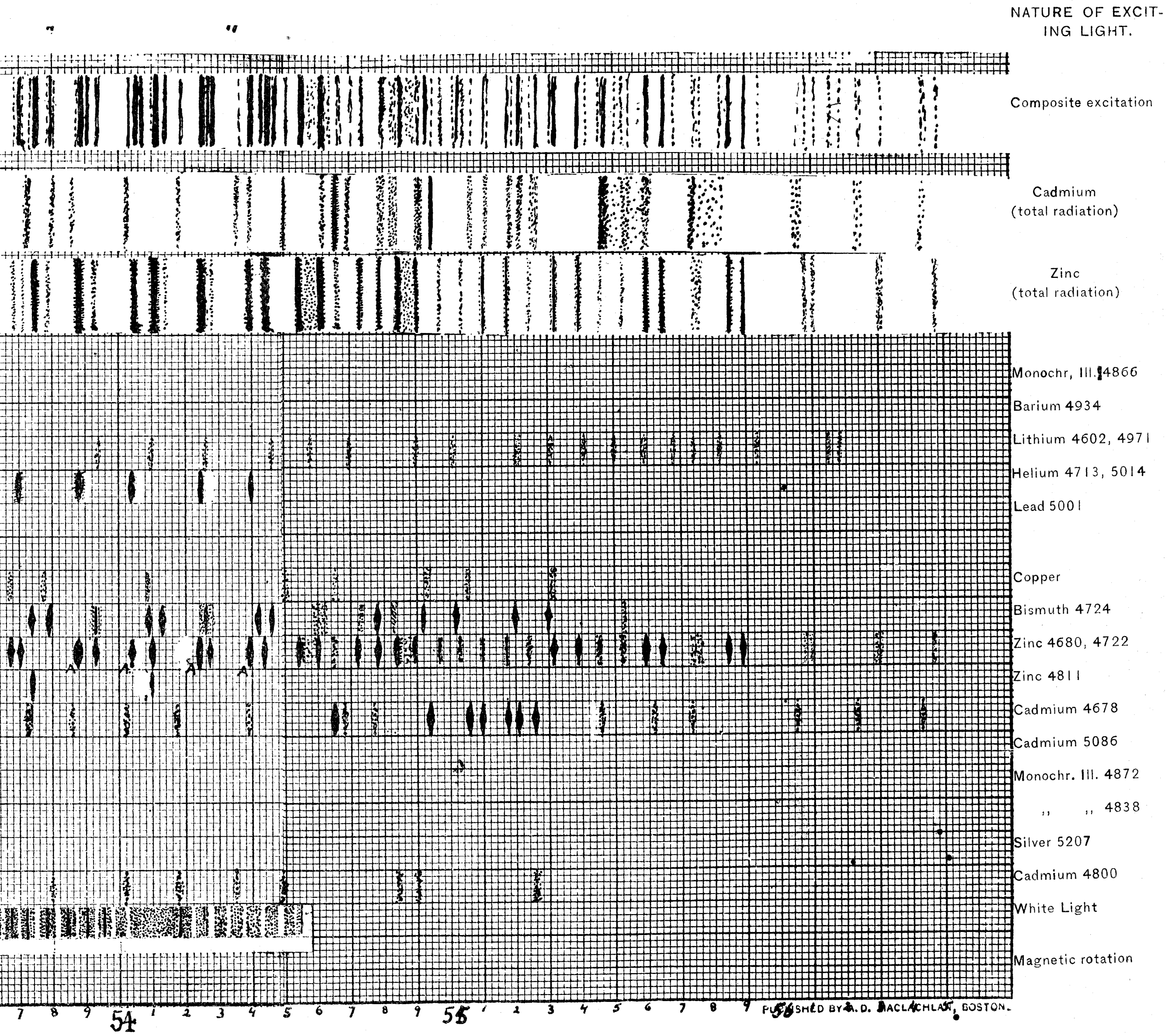
"   "

"   "

"   "

"   "

"   "



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